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Test of an Edison Storage Battery

Electrical Engineering

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TEST OF AN EDISON STORAGE BATTERY

BY

MELVERN D. OVERMIER
ERNEST ALBERT DUNLAP

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE
IN
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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Melvern D. Overmier and Ernest Albert Dunlap

ENTITLED Test of an Edison Storage Battery

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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HEAD OF DEPARTMENT OF Electrical Engineering

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INTRODUCTION.

The Edison Storage battery is the out come of nine years of costly experimentation and persistent toil on the part of the inventor, Thomas A. Edison. The Edison Storage battery to-day represents the highest point of perfection ever attained in storage battery manufacture. This new battery contains no lead and no sulphuric acid. It is a combination of nickel and iron in an alkaline solution; and by its use, the troubles that went with the old lead storage cells are practically eliminated.

DESCRIPTION OF CELLS.

The cells tested were five Edison storage cells, of the Type B-4, the following table gives the dimensions and rate of the cells as given by the makers and also the weight of the cells.

Normal charging Rate - **15 amperes.**

" discharging " 10 amperes.

Outside dimensions of cells in case.

Width - 6 3/4"
Length - 15 1/2"
Height - 8 7/8"

Outside dimensions of a single cell.

Width	2.6"
Length	8.00"
Height	6.75"

Weight of cells complete 40#

" " " alone 34.2 #

POSITIVE ELEMENT.

The positive, or nickel element, is a plate consisting of one row of round rods, or pencils 15 in number. These rods are held in a vertical position by a steel supporting frame. These pencils have flat flanges at the ends, by which they are supported and here electrical connection is made. The frame is slit at the inner horizontal edges, and then folded in such a way as to make individual clamping jaws for each end flange. This clamping is done at great pressure and the result and

plate has great rigidity and strength.

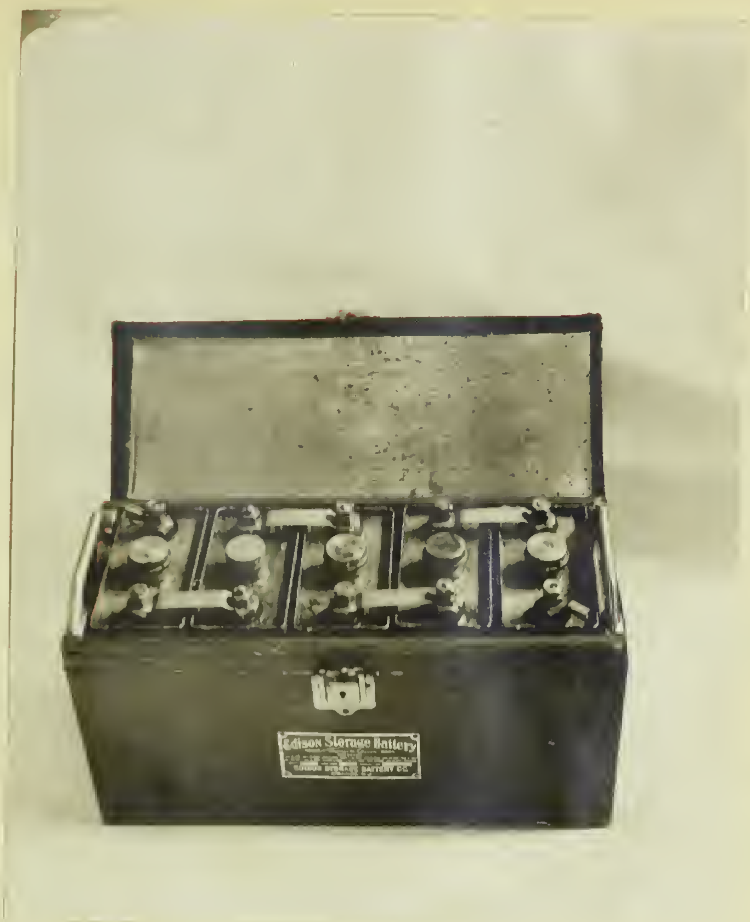
NEGATIVE ELEMENT.

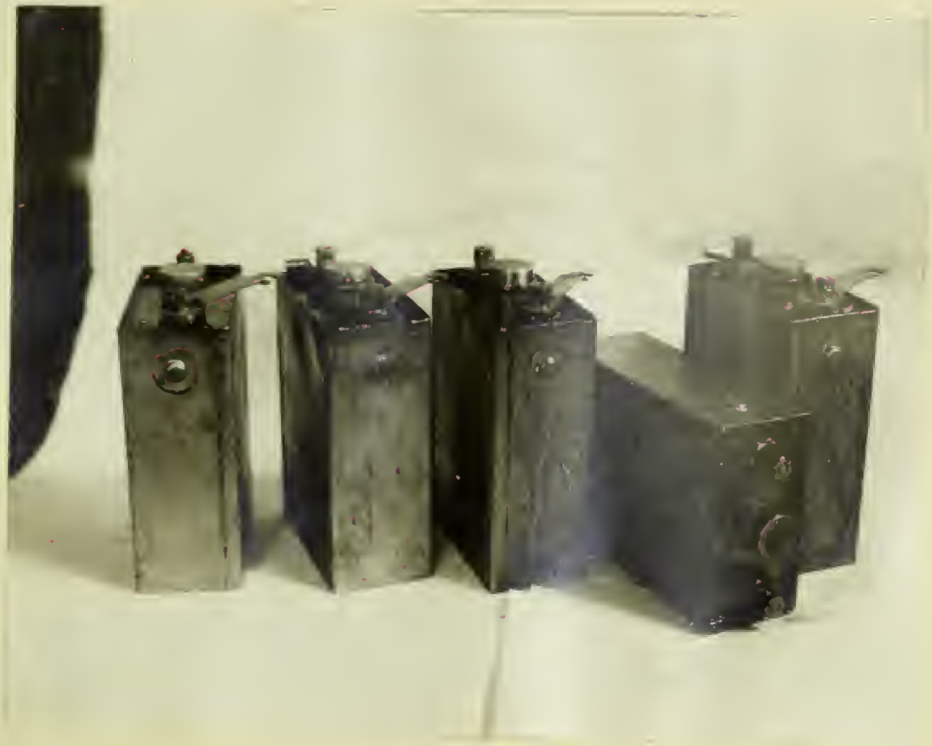
The negative, or iron plate, has the flat pocket construction, and contains sixteen pockets, each pocket being one-half inch by three inches long, and having a maximum thickness of a little more than one-eighth of an inch.

ELECTROLYTE.

The electrolyte of the Edison storage cell consists of a twenty-one per cent. solution of potassium hydrate having in addition a small amount of lithium hydrate.

The Edison cell has an air tight cover, a valve being provided for the escape of gas. Practically no water is lost by evaporation, therefore, a battery can be left idle for months without attention and there will be no danger of the solution becoming low. Some water is lost, however when the battery is working. This results from over charging, for any current which is not used to effect the chemical changes at the electrodes goes to produce hydrogen and oxygen which are emitted as gas. So it is necessary, from time to time, to add small quantities of distilled water.


Edison Storage Battery
Edison Storage Battery Co.



TESTS.

Tests No. 1 & No. 2 :- Capacity and efficiency tests at normal rates of fifteen amperes charging and ten amperes discharging.

Tests No. 3 & No. 4 :- Capacity and efficiency tests at fifteen amperes charging and thirty amperes discharging.

Test No. 5 :- Capacity and efficiency test at twenty amperes charging and thirty amperes discharging.

Test No. 6 :- Capacity and efficiency test at thirty amperes charging and thirty amperes discharging.

Test No. 7 :- Capacity and efficiency test at normal charge and discharge with constant temperature of seven degrees centigrade.

Test No. 8 :- Capacity and efficiency test at normal charge and discharge with constant temperature of twenty-one degrees centigrade.

Test No. 9 :- Capacity and efficiency test at normal charge and discharge with constant temperature of forty degrees centigrade.

Test No.10 :- Resistance test on normal charge and discharge.

Test No.11 :- Short circuit test of battery.

The manufacturers rate this battery as an eighty ampere hour battery at six and one-half volts. They specify that it shall be charged for ten hours at fifteen amperes and discharged at ten amperes. They claim, however, that these values are more or less arbitrary and have only been decided upon after considering the efficiencies and heat losses at various rates of charge and discharge.

In the following tests, an attempt was made, so far as time permitted, to vary all quantities in their turn and find their subsequent effect upon the capacity and efficiency of the battery.

One of the difficult things to determine, and one which is more or less arbitary, was the point at which to stop the charge or discharge. Naturally, of course, this varies with the rate at which the test is carried on. The cells are tightly encased so that it is next to impossible to determine the voltages between plates, so that about the only thing that could be decided upon was the voltage directly across the binding posts of the battery. To great extent, the same considerations were taken account of in stopping the charge on this battery as in the lead storage cell. It was found on a normal charge of fifteen amperes that in from seven and one-half to eight hours, the voltage took a rapid rise to some point, approximately nine volts, when it stood constant. After this point was reached, when the voltage no longer continued to rise, the current was allowed to flow from one-half to three quarters of an hour longer, when it was assumed that the battery

was charged and the circuit was broken. It was also noticed that just before this point was reached that gas was being emitted very rapidly which also went to show that it was time to stop the charging operation.

The point at which to stop the discharge is also more or less a matter of judgement. In fact, contrary to all precedents in lead storage batteries, the makers claim that discharging the battery down to zero sometimes improves its working condition. This battery, however, is rated at six and one-half volts on discharge, and the makers advise discharging down to six-tenths of this value which gives three and nine-tenths volts. It is seen, on an inspection of the curves which follow, that at the time this point is reached, that the voltage was dropping very rapidly and that in less than five minutes more it would have gone to zero. Outside of one or two of the earlier tests, an attempt was made, in each case, to stop the discharge at this point.

As regards the calculations that were made for each individual set of tests, the ampere hour input or output for any charge or discharge was found by multiplying together the current rate and the time in hours for that particular test. The watt-hour input or output was found by multiplying the ampere hour input or output by the average voltage on charge or discharge respectively. The ampere hour efficiency was found by dividing the ampere hour output by the ampere hour input. The coefficient of drop was found by dividing the average voltage on discharge by the average voltage on charge. The watt-hour efficiency was found by multiplying the ampere hour

efficiency by the coefficient of drop. The watt-hour efficiency may also be found by dividing the watt-hour output by the watt-hour input.

In making the actual tests, the battery was charged from a 110 volt circuit. The cells were placed in series with an ammeter, a large one ohm rheostat and a lamp-bank. A voltmeter was placed directly across the contacts of the battery for measuring the pressure. The lamp-bank was included for cutting down the voltage to something within reasonable limits and the rheostat for making a finer adjustment.

On discharge, the battery was simply connected in series with an ammeter and the one ohm rheostat, the latter being sufficient for controlling the voltage and current. A voltmeter was placed directly across the binding posts of the battery.

Throughout all of the earlier tests, readings of time voltage and current were taken, on the average, every fifteen to thirty minutes during the intermediate part of the tests, while near the beginnings of charge and discharge and the end of discharge readings were taken every two to five minutes.

Throughout all of the tests, a fine adjustment of the current was made just before taking any individual set of readings.

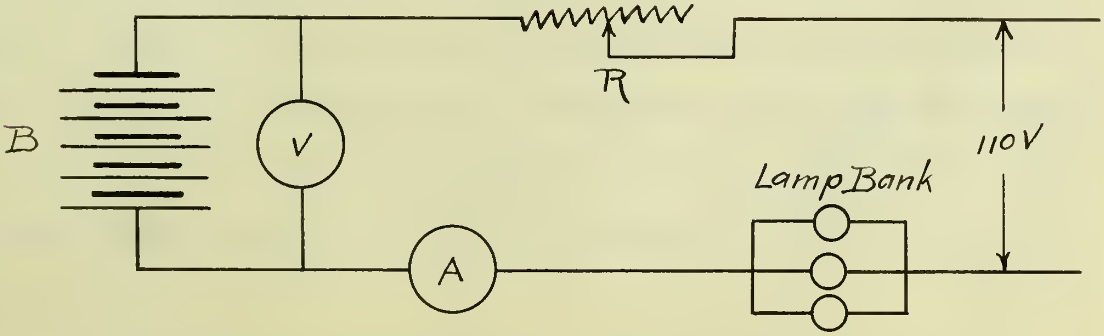


Diagram of Connections of Battery on Charge.

NORMAL CHARGE AND DISCHARGE TESTS.

The object of the present series of tests was to put the battery in good working condition for subsequent tests and to determine the capacity and efficiency of the battery at normal rates of charge and discharge.

When the battery was first set up it was given a normal charge at fifteen amperes and discharge at ten amperes, the charge lasting for about eight hours. No record was kept of the results of this test. It was directly after this test that the two following normal charges and discharges were run. In the first of the following series, the advice of the makers was adhered to rigidly, and the battery was given a charge for ten hours at fifteen amperes. In reality, if we are to judge anything by the voltage, the battery became charged in from eight to eight and one-half hours. During the last two and one-half hours of the charge, gas was emitted very rapidly which also indicated a rather high overcharge. The manufacturers, however, advise giving a new battery a high overcharge before use and a repetition of this from time to time. The battery was discharged at the normal rate of ten amperes.

The battery was then allowed to stand for one week and again charged at the normal rate of fifteen amperes, but in this test, the considerations discussed under the headings of tests, for the time of stopping the charge, were taken into account. The battery was then discharged at the normal rate of ten amperes.

CHARGE AT 15 AMPERES.

Time	Time hrs.-min.	I	E
8:30	0:00	15	8.2
8:33	0:03	"	8.3
8:36	0:06	"	8.38
8:40	0:10	"	8.50
8:43	0:13	"	8.71
8:45	0:15	"	8.81
8:50	0:20	"	8.90
9:00	0:30	"	8.93
9:10	0:40	"	8.92
9:20	0:50	"	8.93
10:00	0:60	"	8.92
10:10	1:10	"	8.90
10:20	1:20	"	8.88
10:30	1:30	"	8.85
10:45	1:45	"	8.85
11:00	2:00	"	8.85
11:15	2:15	"	8.85
11:30	2:30	"	8.86
11:45	2:45	"	8.91
12:00	3:00	"	8.93
12:15	3:15	"	8.95
12:30	3:30	"	8.97
12:45	3:45	"	8.99
1:00	4:00	"	8.98

Time	Time hr.-min.	I	E
1:30	4:30	15	8.95
2:00	5:00	"	8.94
2:30	5:30	"	8.92
3:00	6:00	"	8.92
3:30	6:30	"	8.95
4:00	7:00	"	8.99
4:30	7:30	"	9.02
5:00	8:00	"	9.03
5:30	8:30	"	9.04
6:00	9:00	"	9.04
6:30	9:30	"	9.03
7:00	10:00	"	9.03

DISCHARGE AT 10 AMPERES.

Time	Time hr.-min.	I	E
8:15	0:00	10	6.66
8:18	0:03	"	6.60
8:21	0:06	"	6.50
8:24	0:09	"	6.42
8:27	0:12	"	6.41
8:30	0:15	"	6.38
8:35	0:20	"	6.36
8:40	0:25	"	6.32
8:45	0:30	"	6.30
8:50	0:35	"	6.30
9:00	0:45	"	6.30
9:10	0:55	"	6.26
9:20	1:05	"	6.23
9:30	1:15	"	6.20
9:45	1:30	"	6.12
10:00	1:45	"	6.10
10:15	2:00	"	6.10
10:30	2:15	"	6.08
10:45	2:30	"	6.04
11:00	2:45	"	6.02
11:15	3:00	"	5.93
11:30	3:15	"	5.89
11:45	3:30	"	5.88

Time	Time hr.-min.	I	E
12:00	3:45	10	5.87
12:10	3:55	"	5.86
12:30	4:15	"	5.84
12:45	4:30	"	5.82
1:00	4:45	"	5.81
1:15	5:00	"	5.79
1:30	5:15	"	5.78
1:45	5:30	"	5.72
2:00	5:45	"	5.63
2:15	6:00	"	5.61
2:30	6:15	"	5.53
2:45	6:30	"	5.42
3:00	6:45	"	5.41
3:10	6:55	"	5.41
3:20	7:05	"	5.41
3:30	7:15	"	5.40
3:35	7:20	"	5.38
3:40	7:25	"	5.57
3:45	7:30	"	5.36
3:50	7:35	"	5.30
3:55	7:40	"	5.23
4:00	7:45	"	5.21
4:05	7:50	"	5.20
4:10	7:55	"	5.20
4:15	8:00	"	5.20
4:20	8:05	"	5.20

Time	Time hr.-min.	I	E
4:33	8:18	10	5.00
4:52	8:37	"	4.75
5:03	8:48	"	4.50
5:08	8:53	"	4.25
5:09	8:54	"	3:9

CHARGE AT 15 AMPERES.

Time	Time hr.-min.	I	E
11:40	0:00	15	8.35
11:43	0:03	"	8.50
11:46	0:06	"	8.65
11:55	0:15	"	8.72
12:00	0:20	"	8.72
12:05	0:25	"	8.73
12:10	0:30	"	8.72
12:15	0:35	"	8.71
12:25	0:45	"	8.69
12:35	0:55	"	8.66
12:50	1:10	"	8.64
1:05	1:25	"	8.60
1:20	1:40	"	8.60
1:35	1:55	"	8.57
1:50	2:10	"	8.57
2:05	2:25	"	8.57
2:20	2:40	"	8.56
2:35	2:55	"	8.56
2:50	3:10	"	8.57
3:15	3:35	"	8.56
3:45	4:05	"	8.56
4:15	4:35	"	8.57
4:45	5:05	"	8.58
5:15	5:35	"	8.60

Time	Time hr.-min.	I	E
5:45	6:05	15	8.63
6:00	6:20	"	8.70
6:15	6:35	"	8.72
6:30	6:50	"	8.74
6:45	7:05	"	8.74
7:00	7:20	"	8.74
7:15	7:35	"	8.74

DISCHARGE AT 10 AMPERES.

Time	Time hr.-min.	I	E
8:15	0:00	10	6.90
8:18	0:03	"	6.80
8:21	0:06	"	6.75
8:24	0:09	"	6.70
8:27	0:12	"	6.67
8:30	0:15	"	6.65
8:36	0:21	"	6.61
8:40	0:25	"	6.60
8:50	0:35	"	6.52
9:00	0:45	"	6.49
9:10	0:55	"	6.44
9:20	1:05	"	6.39
9:30	1:15	"	6.36
9:45	1:30	"	6.31
10:00	1:45	"	6.27
10:15	2:00	"	6.24
10:30	2:15	"	6.19
10:45	2:30	"	6.17
11:00	2:45	"	6.15
11:15	3:00	"	6.12
11:30	3:15	"	6.09
11:45	3:30	"	6.07
12:00	3:45	"	6.05
12:15	4:00	"	6.02

	Time		
Time	hr.-min.	I	E
12:30	4:15	10	6.00
12:45	4:30	"	5.98
1:00	4:45	"	5.95
1:15	5:00	"	5.92
1:30	5:15	"	5.90
1:45	5:30	"	5.87
2:00	5:45	"	5.84
2:15	6:00	"	5.80
2:30	6:15	"	5.75
2:45	6:30	"	5.70
3:00	6:45	"	5.63
3:15	7:00	"	5.56
3:30	7:15	"	5.50
3:45	7:30	"	5.44
4:00	7:45	"	5.35
4:15	8:00	"	5.28
4:30	8:15	"	5.18
4:40	8:25	"	5.10
4:50	8:35	"	5.00
4:55	8:40	"	4.91
5:00	8:45	"	4.82
5:05	8:50	"	4.72
5:10	8.55	"	4.53
5:13	8.58	"	4.23

TEST NO. 1.

CHARGE :--

I = 15 amperes.

E (average) = 8.869

Time of charge = 10 hours.

Ampere hour input = 150

Watt-hour input = 1330

DISCHARGE :-

I = 10 amperes.

E (average) = 5.818

Time of discharge = 8.9 hours.

Ampere hour output= 89

Watt-hour output= 518

Ampere hour efficiency = 59.3 %

Coefficient of drop = .657

Watt-hour efficiency = 39.0 %

TEST NO. 2.

CHARGE :-

I = 15 amperes.

E (average) = 8.63 volts.

Time of charge = 7.583 hours.

Ampere hour input = 113.6

Watt-hour input = 982.2

DISCHARGE :-

I = 10 amperes.

E (average) = 5.898

Time of discharge = 8.97 hours.

Ampere hour output = 89.7

Watt-hour output = 528

Ampere hour efficiency = 79.3 %

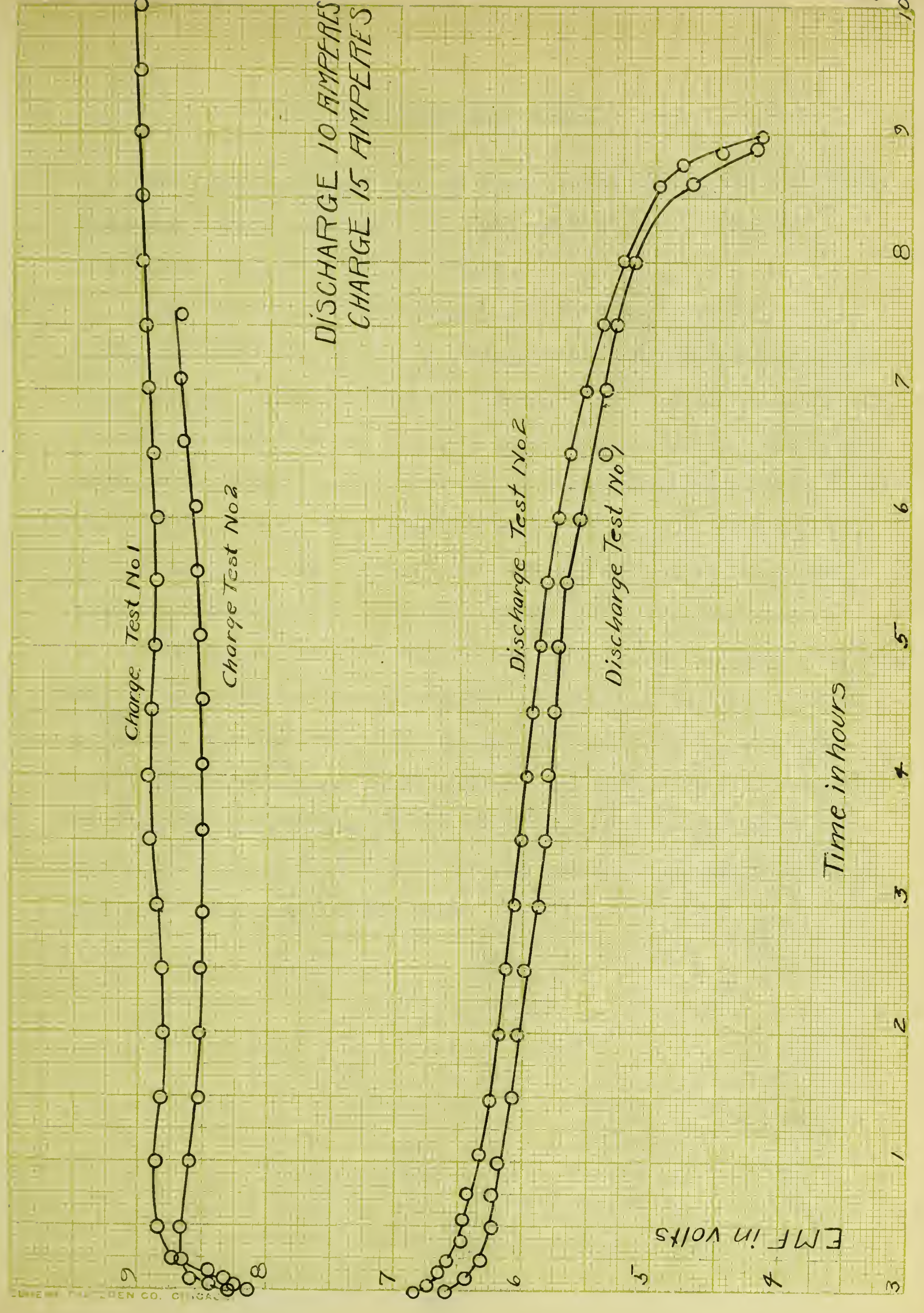
Coefficient of drop = .683

Watt-hour efficiency = 54.2 %

CONCLUSIONS.

It is seen by comparison that a long overcharge very materially lowers the efficiency of the battery for that particular charge and discharge, or in other words, the longer the charge the lower will be the efficiency. In the first test in which the charge ran for ten hours, the ampere hour efficiency is 59.3 % as against 79.3 % for the second charge and discharge. In the first test, the watt-hour efficiency is 39 % as against 54.2 % for the second test.

The ampere hour and watt-hour outputs for the two different tests are a little in doubt. Both outputs in the second test are slightly in excess of those of the first test. It is doubtful if this will hold rigidly true. The first charge and discharge gives an ampere hour and watt-hour output equal to 89 and 518 respectively as against an ampere hour and watt-hour output of 89.7 and 528 respectively in the second charge and discharge.


DISCHARGE 10 AMPERES
CHARGE 15 AMPERES
Charge Test No 1
Charge Test No 2
Discharge Test No 2
Discharge Test No 1
Time in hours
EMF in volts
0
1
2
3
4
5
6
7
8
9
10
9
8
7
6
5
4
3

HIGH DISCHARGE TESTS.

The object of this set of tests is to determine the effect upon the battery and upon its voltage characteristics of a continuous high rate of discharge.

This series of tests followed, after an interval of one week, the first two tests on normal charge and discharge, the first being a high overcharge, in which the battery was allowed to charge for ten hours at fifteen amperes, which is the normal rate, and discharge at ten amperes. The second test was a charge at fifteen amperes for approximately eight hours and discharge at ten amperes. The battery was then assumed to be in normal working condition for starting the present series of tests.

In this series the battery was charged at the normal rate of fifteen amperes and discharged at three times normal rate, or thirty amperes. The battery was then allowed to cool off, after which it was again charged at the normal rate of fifteen amperes and discharged at thirty amperes. As in the previous tests, readings of time voltage and current were taken throughout each charge and discharge.

CHARGE AT 15 AMPERES.

Time	Time hr.-min.	I	E
11:52	0:00	15	7.12
11:55	0:03	"	7.38
11:58	0:06	"	7.50
12.01	0:09	"	7.60
12:04	0:12	"	7.70
12:07	0:15	"	7.76
12:10	0:18	"	7.78
12:15	0:23	"	7.96
12:20	0:28	"	8.02
12:25	0:33	"	8.12
12:30	0:38	"	8.18
12:40	0:48	"	8.22
12:50	0:58	"	8.29
1:00	1:08	"	8.31
1:15	1:23	"	8:30
1:30	1:38	"	8.29
1:45	1:53	"	8.29
2:00	2:08	"	8.29
2:15	2:23	"	8.30
2:30	2:38	"	8.32
2:45	2:53	"	8.35
3:00	3:08	"	8.40
3:15	3:23	"	8.43
3:30	3:38	"	8.47

Time	Time hr.-min.	I	E
3:45	3:53	15	8.50
4:00	4:08	"	8.53
4:15	4:28	"	8.56
4:30	4:38	"	8.60
4:45	4:53	"	8.66
5:00	5:08	"	8.71
5:15	5:23	"	8.80
5:30	5:38	"	8.85
5:45	5:53	"	8.90
6:00	6:08	"	8.97
6:15	6:23	"	8.97
6:30	6:38	"	8.97
6:45	6:53	"	8.97

DISCHARGE AT 30 AMPERES.

Time	Time hr.-min.	I	E
9:00	0:00	30	6.31
9:02	0:02	"	6.10
9:05	0:05	"	5.95
9:10	0:10	"	5.82
9:16	0:16	"	5.72
9:20	0:20	"	5.68
9:30	0:30	"	5.57
9:50	0:50	"	5.42
10:00	1:00	"	5.34
10:15	1:15	"	5.21
10:30	1:30	"	5.02
10:45	1:45	"	4.77
11:00	2:00	"	4.41
11:08	2:08	"	4.18
11:13	2:11	"	3.98
11:18	2:18	"	3.90
11:20	2:20	"	3.85

CHARGE AT 15 AMPERES.

Time	Time hr.-min.	I	E
12:21	0:00	15	8.25
12:24	0:03	"	8.60
12:27	0:06	"	8.78
12:33	0:12	"	8.91
12:39	0:18	"	8.90
12:52	0:31	"	8.76
1:00	0:39	"	8.73
1:10	0:49	"	8.70
1:24	1:03	"	8.70
1:30	1:09	"	8.69
1:45	1:24	"	8.67
2:00	1:39	"	8.65
2:30	2:09	"	8.65
3:00	2:39	"	8.66
3:30	3:09	"	8.67
4:00	3:39	"	8.68
4:30	4:09	"	8.70
5:00	4:39	"	8.74
5:30	5:09	"	8.79
6:00	5:39	"	8.80
6:30	6:09	"	8.85
7:00	6:39	"	8.95
7:15	6:54	"	9.00
7:30	7:09	"	9.03

Time	Time hr.-min.	I	E
7:45	7:24	15	9.04
8:00	7:39	"	9.05
8:15	7:54	"	9.05

DISCHARGE AT 30 AMPERES-

Time	Time hr.-min.	I	E
8:00	0:00	30	6.30
8:03	0:03	"	6.06
8:06	0:06	"	5.95
8:09	0:09	"	5.90
8:12	0:12	"	5.81
8:15	0:15	"	5.80
8:22	0:22	"	5.70
8:30	0:30	"	5.65
8:40	0:40	"	5.57
8:50	0:50	"	5.51
9:00	1:00	"	5.45
9:10	1:10	"	5.39
9:20	1:20	"	5.28
9:30	1:30	"	5.19
9:38	1:38	"	5.00
9:46	1:46	"	4.90
9:53	1:53	"	4.78
9:58	1:58	"	4.67
10:07	2:07	"	4.50
10:13	2:13	"	4.31
10:21	2:21	"	3.95
10:25	2:25	"	3.75
10:30	2:30	"	3.49

FIRST CHARGE AT NORMAL RATE :-

I= 15 amperes

E (average)= 8.74 volts

Time of charge= 7.15 hours

Ampere hour input =107.5

Watt-hour input = 885

FIRST DISCHARGE AT THREE TIMES NORMAL :-

I= 30 amperes

E (average)= 5.13 volts

Time of Discharge = 2.33 hours

Ampere hour output= 69.8

Watt-hour output = 359

Coefficient of drop= .587

Ampere hour Efficiency = 65 %

Watt hour Efficiency = 38.1 %

SECOND CHARGE AT NORMAL RATE :-

I= 15

E (average)= 8.31 volts

Time of charge = 6.88 hours

Ampere hour input= 103.5

Watt hour input = 859.

SECOND DISCHARGE AT THREE TIMES NORMAL :-

I = 30 amperes

E (average) = 5.22 volts

Time of discharge = 2.5 hours

Ampere hour output = 75

Watt-hour output = 391.5

Coefficient of drop = .628

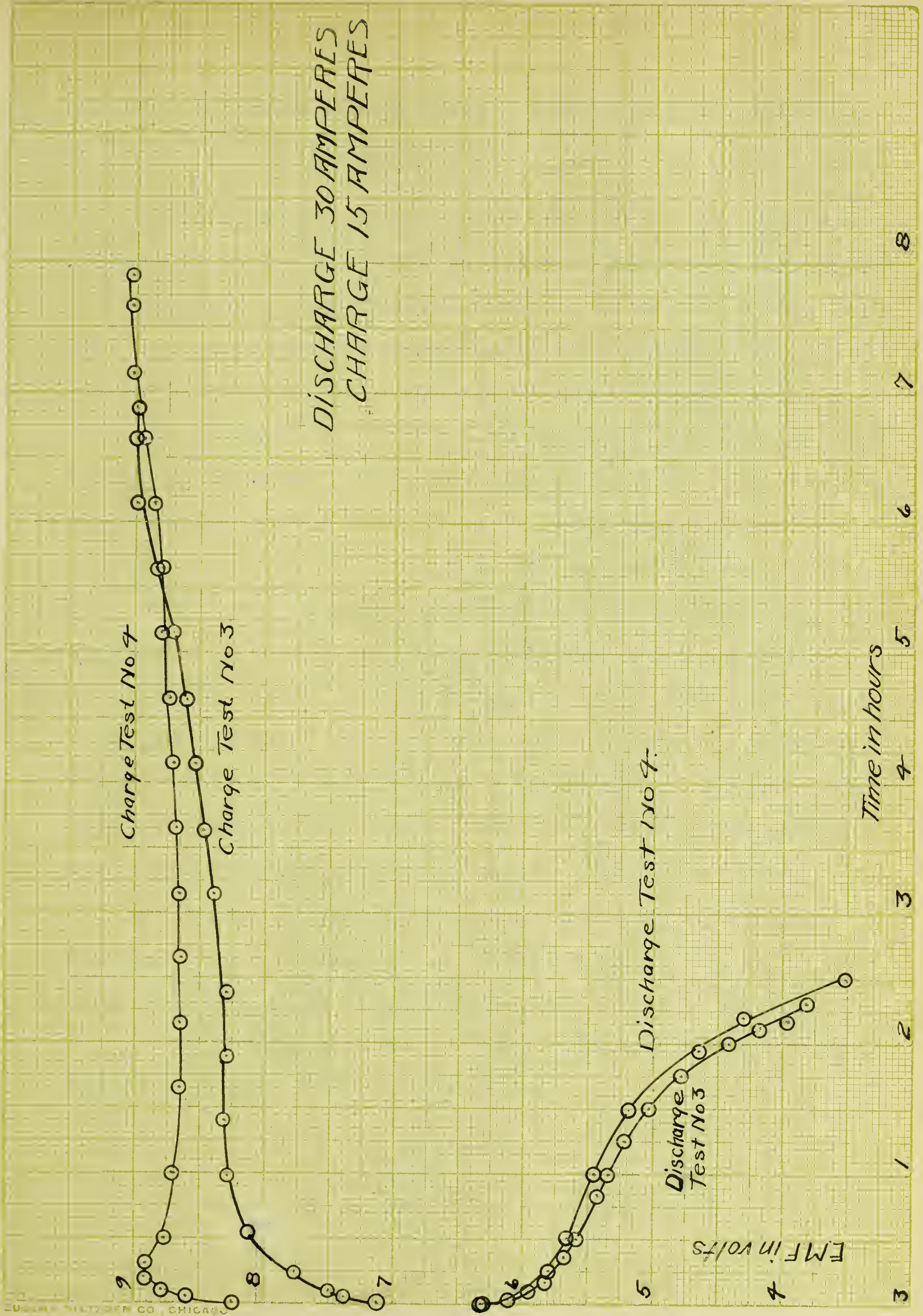
Ampere hour Efficiency = 72.5 %

Watt-hour Efficiency = 45.6 %

CONCLUSIONS.

It is seen, on inspection, that although the two discharge curves give the same general shape, and in fact the second one is slightly higher than the first, the two curves on charge deviate considerably from each other. The curve corresponding to first charge at fifteen amperes is a normal shaped curve, that is, it is such a curve as we would get when the battery is in its normal condition and is being worked at normal rate, while the curve corresponding to the second charge at the same rate starts considerably lower and does not give the sudden rise of voltage as seen in the first curve and which is characteristic of this make of battery.

The conclusions to be drawn are that this rate of discharge is too high for the battery and especially so if the rate is kept up continuously for time after time.


DISCHARGE 30 AMPERES
CHARGE 15 AMPERES
Charge Test No 4
Charge Test No 3
Discharge Test No 4.
Discharge Test No 3
Time in hours
EMF in volts
1
2
3
4
5
6
7
8
3
4
5
6
7
8
9
EUGENE DIETZGEN CO., CHICAGO

CAPACITY AND EFFICIENCY TESTS UNDER HIGH RATES OF CHARGE AND DISCHARGE.

These capacity and efficiency tests at 20 and 30 amperes charging and 30 amperes discharging were made seven days after the completion of tests number 4 and 5. It will be noticed that in those tests that the battery was twice given a high rate of discharge which was equal to three times the normal rate. It was then assumed, due to this high rate, that the battery might not have discharged down to the same point as at normal rate, although the voltage fell off to the same value. It was considered, however, in the following two sets of tests, that this error would be compensated for, due to the fact that both discharges were to take place at the same high rate as in the two previous tests. In this manner, the same error would creep into both tests, if at all, and affect both sets of efficiencies in the same way. For this reason, together with the fact that time was precious, the battery was not given a normal charge and discharge between the last series of tests and those following. The assumptions that have just been made apply rigidly to lead storage cells. Whether they will apply to this type of cell will be discussed.later in a general summary.

As in the previous set of tests, readings of time voltage and current were taken in this series.

CHARGE AT 20 AMPERES.

Time	Time hr.-min.	I	E
8:45	0:00	20	8.32
8:47	0:02	"	8.63
8:50	0:05	"	8.78
8:55	0:10	"	8.92
9:00	0:15	"	8.92
9:03	0:18	"	8.90
9:08	0:23	"	8.85
9:15	0:30	"	8.79
9:30	0:45	"	8.72
9:45	1:00	"	8.70
10:00	1:15	"	8.70
10:15	1:30	"	8.70
10:30	1:45	"	8.72
10:45	2:00	"	8.72
11:00	2:15	"	8.73
11:30	2:30	"	8.75
12:00	3:00	"	8.77
12:30	3:30	"	8.81
1:00	4:00	"	8.97
1:15	4:15	"	9.10
1:30	4:30	"	9.11
1:45	4:45	"	9.12
2:00	5:00	"	9.15
2:15	5:15	"	9.15

DISCHARGE AT 30 AMPERES.

Time	Time hr.-min.	I	E
2:40	0:00	30	6:85
2:43	0:03	"	6:60
2:46	0:06	"	6:47
2:49	0:09	"	6:40
2:54	0:14	"	6:30
3:00	0:20	"	6:20
3:10	0:30	"	6:05
3:25	0:45	"	5:91
3:45	1:05	"	5:76
4:00	1:20	"	5:65
4:15	1:35	"	5:50
4:30	1:50	"	5:33
4:45	2:05	"	5:10
5:00	2:20	"	4.93
5:15	2:35	"	4.62
5:20	2:40	"	4.32
5:25	2:45	"	3:70
5:27	2:47	"	3:51

CHARGE AT 30 AMPERES.

Time	Time hr.-min.	I	E
8:00	0:00	30	8:47
8:03	0:03	"	8:68
8:06	0:06	"	8:80
8:09	0:09	"	8:92
8:15	0:15	"	9:03
8:21	0:21	"	9:00
8:30	0:30	"	8:92
8:45	0:45	"	8:88
9:00	1:00	"	8:88
9:15	1:15	"	8:88
9:45	1:45	"	8:89
10:00	2:00	"	8:90
10:15	2:15	"	8:90
10:30	2:30	"	8:96
10:45	2:45	"	9:07
11:00	3:00	"	9:21
11:15	3:15	"	9:30
11:30	3:30	"	9:30

DISCHARGE AT 30 AMPERES.

Time	Time hr.-min.	I	E
12:22	0:00	30	6.70
12:25	0:03	"	6.53
12:30	0:08	"	6.39
12:35	0:13	"	6.30
12:40	0:18	"	6.23
12:50	0:28	"	6.10
1:00	0:38	"	6.00
1:15	0:53	"	5.87
1:30	1:08	"	5.79
1:45	I:23	"	5.68
2:00	1:38	"	5.55
2:15	1:53	"	5.35
2:30	2:08	"	5.11
2:45	2:23	"	4.80
2:50	2:28	"	4.47
2:53	2:31	"	4.00

TEST NO. 5.

CHARGE AT 20 AMPERES.

I = 20 amperes.

E (average) = 8.87

Time of charge = 5.25 hours

Ampere hour input = 105

Watt-hour input = 932

DISCHARGE AT 30 AMPERES.

I = 30 amperes.

E (average) = 5.429

Time of discharge = 2.783 hours.

Ampere hour output = 83.6

Watt-hour output = 454

Ampere hour efficiency = 79.7 %

Coefficient of drop = .612

Watt-hour efficiency = 48.7 %

TEST NO. 6.

CHARGE AT 30 AMPERES.

I = 30 amperes.

E (average) = 8.963

Time of charge = 3.50 hours

Ampere hour input = 105

Watt-hour input = 942

DISCHARGE AT 30 AMPERES.

I = 30 amperes

E (average) = 5.51 volts.

Ampere hour output= 75.5

Watt-hour output = 416

Ampere hour efficiency = 72.0 %

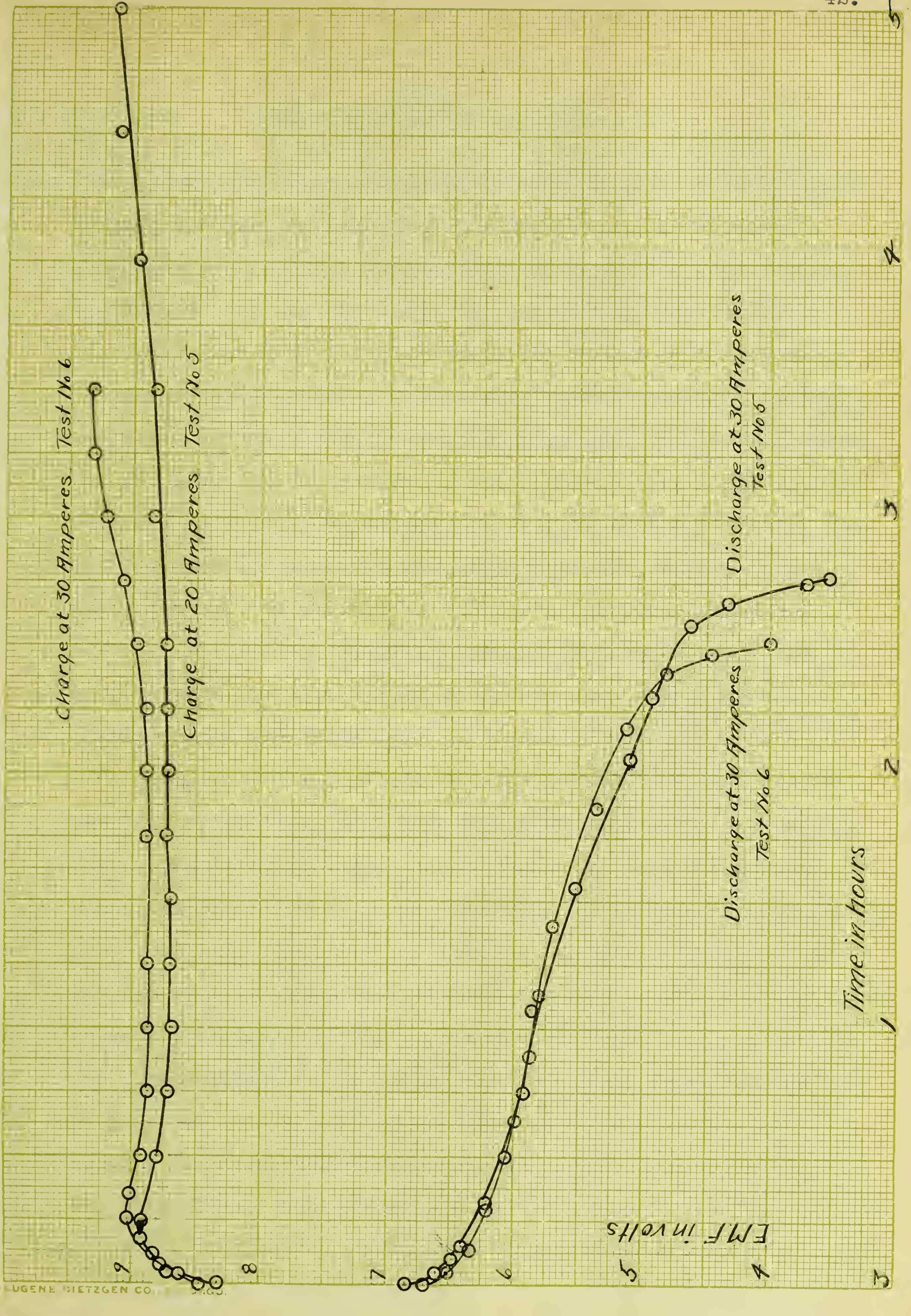
Coefficient of drop = .615

Watt-hour efficiency = 44.2 %

CONCLUSIONS.

From an inspection of the curve and the calculated data, it would seem that the twenty ampere rate of charge gives the better rate of the two,for in this case,the battery gave an ampere hour output = 83.6 which exceeds the manufacturer's rating of the battery. In the thirty ampere rate charge, the ampere hour output was less than the rating of the battery by 4.5 ampere hours, 75.5 ampere hours being the output in this particular case. Likewise, the twenty ampere rate gave an ampere hour efficiency equal to 79.7 per cent. as against 72 per cent. for the thirty ampere rate. Also, the twenty ampere rate gave a watt-hour efficiency equal to 48.7 per cent. as against 44.2 per cent. for the thirty ampere rate of charge.

The same considerations might here be applied to the charging rate as were previously applied to the discharging rate, that is; that the thirty ampere rate was too high to permit the battery to become fully charged even though the voltage seemed to indicate that it was charged. This, of course, if true at all, is due to the fact that the electrolyte has not time to become throughly worked into the grids of the battery.


Charge at 30 Amperes Test No. 6
Charge at 20 Amperes Test No 5
Discharge at 30 Amperes Test No 5
Discharge at 30 Amperes Test No 6
Time in hours
EMF in volts
1
2
3
4
5
3
4
5
6
7
8
9
EUGENE DIETZGEN CO.

CONSTANT TEMPERATURE TESTS.

The object of the following series of three sets of tests is to determine the effect of temperature on the voltage characteristics and the consequent effect on the capacity and the ampere hour and watt-hour efficiencies of the battery.

This series of tests followed the series on a high rate of charge and discharge. It was then assumed that the battery would, in all probability, contain a partial charge, due to the previous rapid discharges, and consequently, would not be in a normal working condition. To obivate this difficulty, and put the battery back in a normal condition, a normal charge and discharge was run before beginning the present series.

In each of the following sets of tests an attempt was made to keep the temperature as nearly constant as possible during charge and discharge.

During the first charge of this series, the temperature was kept constant at approximately seven degrees centigrade while, the discharge was carried out at an almost constant temperature of five degrees centigrade. The test was accomplished by setting the batteries in a wooden box and packing cracked ice around them which accounts for the difference in temperature between charge and discharge. It was very difficult to control the temperature by this method within two or three degrees due to the fact that about the only recourse that was had for keeping the temperature down, lay in merely packing the ice and maintaining approximately a constant level with, or slightly above the tops of the cells. The temperature was taken by

removing the cap from one of the cells and inserting a thermometer through the opening. A slight error was probably introduced in this way, due to the fact that, on account of the close proximity of the plates, the bulb of the thermometer was only allowed to dip from one-half to three-quarters of an inch below the surface of the liquid. Thus, it is seen that, on account of the warmer liquids rising to the surface, the temperature at this point was slightly in excess of that at the bottom.

The second charge and discharge was accomplished by allowing the batteries to stand in water up to within a quarter of an inch of their tops. They were arranged in the form of a circle so that an electric bulb could be inserted in the water in their midst, and yet be at approximately an equal distance from all the batteries. The temperature was kept constant at twenty-one degrees centigrade by switching on the lamp for a few minutes at a time to raise the temperature or by letting cold water into the bottom of the vessel by means of a rubber tube to lower the temperature. Throughout this and the following set of tests, the water was stirred every few minutes.

The third charge and discharge was accomplished along the same lines, excepting four electric bulbs instead of one were used. In this test, the temperature was kept constant at forty degrees centigrade; both for charge and discharge.

CHARGE AT 15 AMPERES.

Time	Time hr.-min.	I	E	Temp. Deg. C.
5:05	0:00	15	8.47	8
5:10	0:05	"	8.62	8
5:15	0:10	"	8.80	8
5:20	0:15	"	8.84	8
5:35	0:30	"	8.82	8
5:45	0:40	"	8.80	8
6:00	0:55	"	8.66	8
6.15	1:10	"	8.65	8
6:30	1:25	"	8.67	8
7:00	1:55	"	8.70	8
7:30	2:25	"	8.71	8
8:00	2:55	"	8.75	8
8:30	3:25	"	8.76	8
9:00	3:55	"	8.85	8
9:30	4:25	"	9.14	7
10.00	4:55	"	9.22	6
10:07	5:02	"	9.22	6
10:17	5:12	"	9.24	6
10:27	5:24	"	9.25	6
10:37	5:34	"	9.25	7
10:52	5:49	"	9.25	8
11:07	6:04	"	9.25	8

DISCHARGE AT 10 AMPERES.

Time	Time hr.-min.	I	E	Temp. Deg. C.
8.00	0:00	10	6.87	5
8:03	0:03	"	6.67	5
8:06	0:06	"	6.52	5
8:09	0:09	"	6.42	5
8:15	0:15	"	6.37	5
8:23	0:23	"	6.27	5
8:35	0:35	"	6.20	5
8:40	0:40	"	6.18	5
8:45	0:45	"	6.16	5
9:00	1:00	"	6.11	5
9:15	1:15	"	6.03	5
9:30	1:30	"	6.83	5
9:45	1:45	"	6.78	5
10.00	2:00	"	5.73	5
10:15	2:15	"	5.69	5
10:30	2:30	"	5.67	5
10:45	2:45	"	5.65	5
11:00	3:00	"	5.62	5
11:15	3:15	"	5.61	5
11:30	3:30	"	5.59	5
11:45	3:45	"	5.57	5
12:00	4:00	"	5.57	5
12:30	4:30	"	5.50	5
12:45	4:45	"	5.48	5

Time	Time hr.-min.	I	E	Temp. Deg. C.
1:00	5:00	10	5.37	5
1:15	5:15	"	5.28	5
1:30	5:30	"	5.24	5
1:45	5:45	"	5.15	5
2:00	6:00	"	5.01	5
2:13	6:13	"	4.82	5
2:18	6:18	"	4.62	5
2:22	6:22	"	4.07	5
2:23	6:23	"	3.82	5

CHARGE AT 15 AMPERES.

Time	Time hr.-min.	I	E	Temp. Deg. C.
9:05	0:00	15	8.55	21
9:08	0:03	"	8.59	"
9:15	0:10	"	8.60	"
9:25	0:20	"	8.62	"
9:30	0:25	"	8.61	"
9:45	0:40	"	8.58	"
10:00	0:55	"	8.55	"
10:15	1:10	"	8.55	"
10:30	1:25	"	8.55	"
10:45	1:40	"	8.57	"
11:00	1:55	"	8.59	"
11:15	2:10	"	8.61	"
11:30	2:25	"	8.63	"
11:45	2:40	"	8.65	"
12:10	3:05	"	8.67	"
12:30	3:25	"	8.68	"
12:50	3:45	"	8.71	"
1:10	4:05	"	8.74	"
1:15	4:10	"	8.75	"
1:30	4:25	"	8.78	"
1:45	4:40	"	8.80	"
2:00	4:55	"	8.85	"
2:15	5:10	"	8.90	"
2:30	5:25	"	8.98	"

Time	Time hr.-min.	I	E	Temp. Deg. C.
2:45	5:40	15	9.08	21
3:00	5:55	"	9.15	21
3:15	6:10	"	9.17	21
3:30	6:25	"	9.24	21
3:45	6:40	"	9.25	21
4:00	6:55	"	9.25	21
4:15	7:10	"	9.25	21
4:30	7:25	"	9.25	21

DISCHARGE AT 10 AMPERES.

Time	Time hr.-min.	I	E.	Temp. Deg. C.
8:30	0:00	10	6.81	21
8:33	0:03	"	6.65	21
8:36	0:06	"	6.60	21
8:39	0:09	"	6.55	21
8:45	0:15	"	6.53	21
9:00	0:30	"	6.45	21
9:15	0:45	"	6.35	21
9:30	1:00	"	6.29	21
9:45	1:15	"	6.25	21
10:00	1:30	"	2.21	21
10:15	1:45	"	6.17	21
10:30	2:00	"	6.15	21
10:45	2:15	"	6.10	21
11:00	2:30	"	6.05	21
11:15	2:45	"	6.03	21
11:30	3:00	"	6.01	21
11:45	3:15	"	5.97	21
12:00	3:30	"	5.95	21
12:15	3:45	"	5.95	21
12:30	4:00	"	5.94	21
12:45	4:15	"	5.91	21
1:00	4:30	"	5.87	21
1:15	4:45	"	5.85	21
1:30	5:00	"	5.82	21

Time	Time hr.-min.	I	E	Temp. Deg. C.
1:45	5:15	10	5.80	21
2:00	5:30	"	5.75	21
2:15	5:45	"	5.71	21
2:30	6:00	"	5.67	21
2:45	6:15	"	5.63	21
3:00	6:30	"	5.55	21
3:15	6:45	"	5.45	21
3:30	7:00	"	5.37	21
3:45	7:15	"	5.25	21
4:00	7:30	"	4.95	21
4:09	7:39	"	3.75	21

CHARGE AT 15 AMPERES.

Time	Time hr.-min.	I	E	Temp. Deg. C.
8:50	0:00	15	7.59	40
8:53	0:03	"	7.57	40
8.56	0:06	"	7.78	40
9:00	0:10	"	7.79	40
9:15	0:25	"	7.85	40
9:30	0:40	"	7.97	40
9:45	0:55	"	7.99	40
10:00	1:00	"	8.05	40
10:15	1:25	"	8.07	40
10:45	1:55	"	8.08	40
11:00	2:10	"	8.09	40
11:15	2:25	"	8.09	40
11:45	2:55	"	8.10	40
12:00	3:10	"	8.12	40
12:15	3:25	"	8.12	40
12:30	3:40	"	8.13	40
12:45	3:55	"	8.14	40
1:00	4:10	"	8.14	40
1:15	4:25	"	8.15	40
1:30	4:40	"	8.16	40
1:45	4:55	"	8.17	40
2:00	5.10	"	8.19	40
2.15	5.25	"	8.23	40
2:30	5:40	"	7.27	40

	Time			Temp.
Time	hr.-min.	I	E	Deg. C.
2:45	5:55	15	8.29	40
3:00	6:10	"	8.32	40
3:15	6:25	"	8.39	40
3:30	6:40	"	8.41	40
3:45	6:55	"	8.46	40
4:00	7:10	"	8.48	40
4:15	7:25	"	8.51	40
4:30	7:40	"	8.57	40
4:45	7:55	"	8.62	40
5:00	8:10	"	8.67	40
5:15	8:25	"	8.67	40
5:30	8:40	"	8:70	40
5:45	8:55	"	8:70	40
6:00	9.10	"	8.70	40

DISCHARGE AT 10 AMPERES.

Time	Time hr.-min.	I	E	Temp. Deg. C.
6:20	0:00	10	7.17	40
6:23	0:03	"	6.87	40
6:30	0:10	"	6.82	40
6:45	0:25	"	6.77	40
7:00	0:40	"	6.67	40
7:15	0:55	"	6.62	40
7:30	1:10	"	6.52	40
7:45	1:25	"	6.49	40
7:50	1:30	"	6:37	40
8:20	2:00	"	6:32	40
8:45	2:25	"	6.27	40
9:00	2:40	"	6.25	40
9:15	2:55	"	6.22	40
9:30	3:10	"	6.18	40
9:45	3:25	"	6.17	40
10:00	3:40	"	6.16	40
10:15	3:55	"	6.14	40
10:30	4:10	"	6.10	40
10:45	4:25	"	6.08	40
11:00	4:40	"	6.06	40
11:15	4:55	"	6.04	40
11:30	5.10	"	6.01	40
11:45	5:25	"	5.97	40

	Time			Temp.
Time	hr.-min.	I	E	Deg. C.
12:00	5:40	10	5.95	40
12:30	6:10	"	5.92	40
12:45	6:25	"	5.83	40
1:00	6:40	"	5.80	40
1:30	7:10	"	5.77	40
2:00	7:40	"	5.67	40
2:30	8:10	"	5.57	40
2:52	8:32	"	4.87	40
3:00	8:40	"	4.07	40
3:03	8.43	"	3.87	40

SEVEN DEGREES CENTIGRADE.

CHARGE :-

I = 15 amperes

E (average) = 8.92 volts.

Time of charge = 6.067 hours.

Ampere hour input = 91

Watt-hour input = 812

DISCHARGE :-

I = 10 amperes.

E (average) = 5.65 volts.

Time of Discharge = 6.38 hours.

Ampere hour output = 63.8 = 79.8 % of Rated output.

Watt-hour output = 361

Coefficient of Drop = .633

Ampere hour efficiency = 71.0 %

Watt-hour efficiency = 44.9 %

TWENTY-ONE DEGREES CENTIGRADE.

CHARGE :-

I = 15 amperes.

E (average) = 8.525 volts.

Time of charge = 7.417 hours

Ampere hour input = 111.25

Watt-hour input = 948

DISCHARGE :-

I =10 amperes.

E (average) = 5.825 volts

Time of Discharge = 7.65 hours

Ampere hour output = 76.5 = 95.7 % of rated output.

Watt-hour output = 447

Ampere hour efficiency = 68.75 %

Coefficient of drop = .683

Watt-hour efficiency = 47.0 %

FORTY DEGREES CENTIGRADE.

CHARGE :-

I = 15 amperes.

E (average) = 8.225 volts.

Time of charge = 9.167 hours.

Ampere hour input = 137.5

Watt-hour input = 1130

DISCHARGE :-

I= 10 amperes.

E (average) = 5.975 volts.

Time of discharge =8.767 hours.

Ampere hour output = 87.67 ampere hrs.= 109.5 % of Rated output.

Watt-hour output= 523

Ampere hour efficiency = 63.75 %

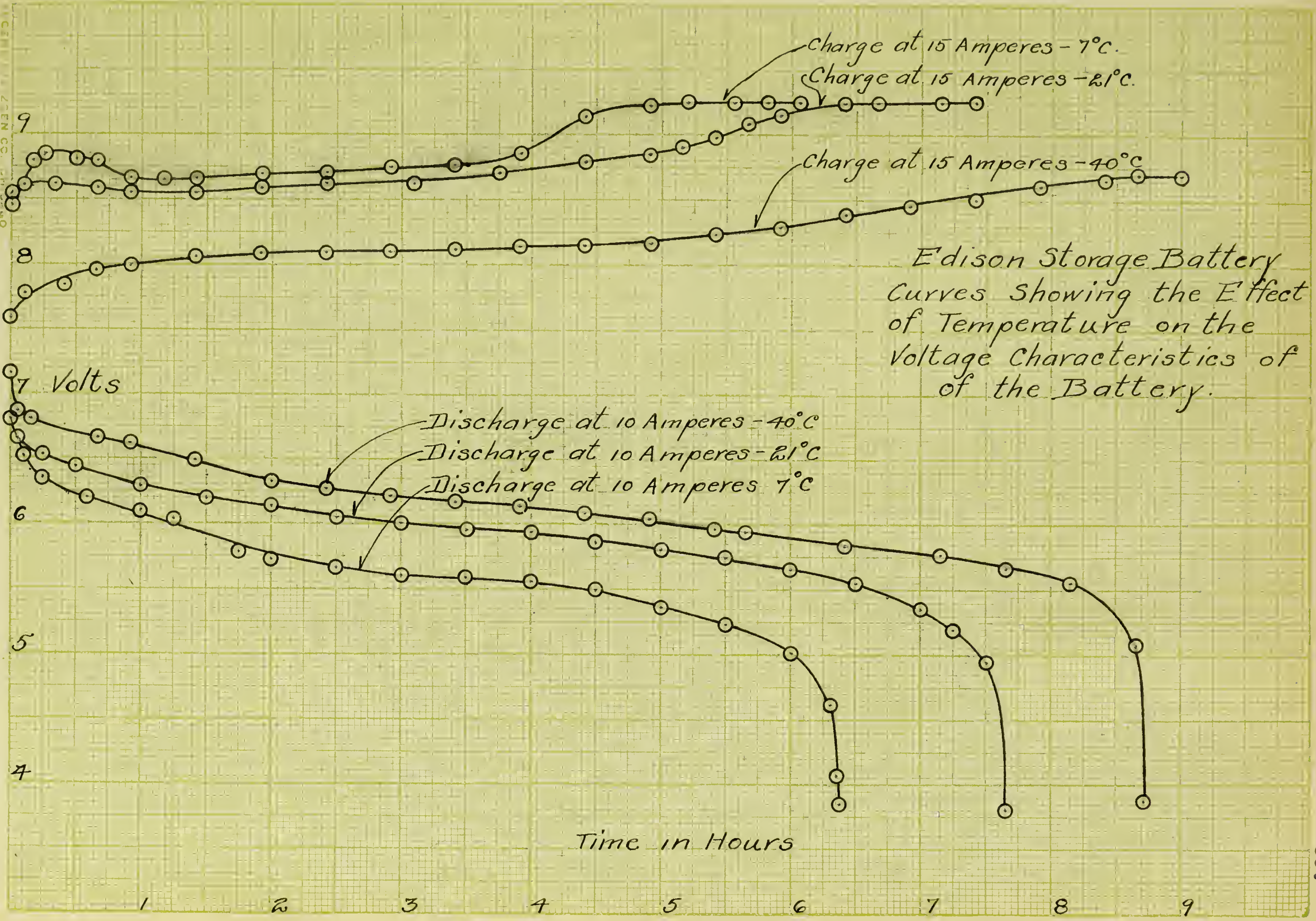
Coefficient of drop = .727

Watt-hour efficiency = 46.25 %

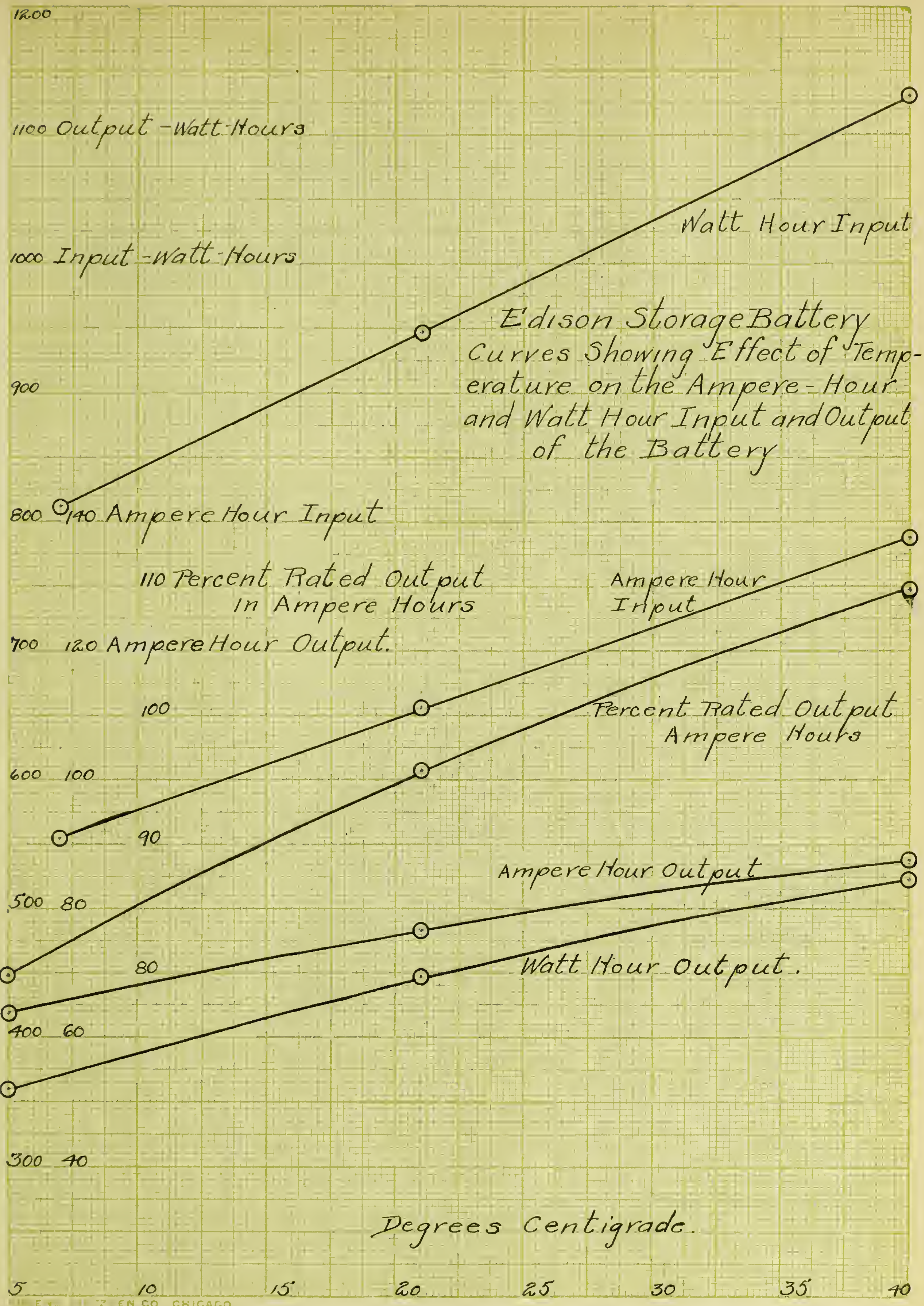
CONCLUSIONS.

It appears from an inspection of the curve sheet that the ampere hour input and output also the watt-hour input and output increase in a little less than a direct ratio with the increase in temperature. The watt-hour input curve shows almost a straight line through the three points. It is possible, of course, that if time had permitted to run more tests, thus locating more points, that the curves would have deviated slightly from their present general shape. In only one of these tests was the rated output of the battery exceeded or even equaled. The seven degree test gave an ampere hour output only 80 % of the rated output of the battery.

The ampere hour efficiency decreases in not quite a direct ratio with the increase in temperature. The watt-hour efficiency increases slightly at first and then begins to decrease with increase in temperature, giving a maximum efficiency at about twenty-five degrees C.

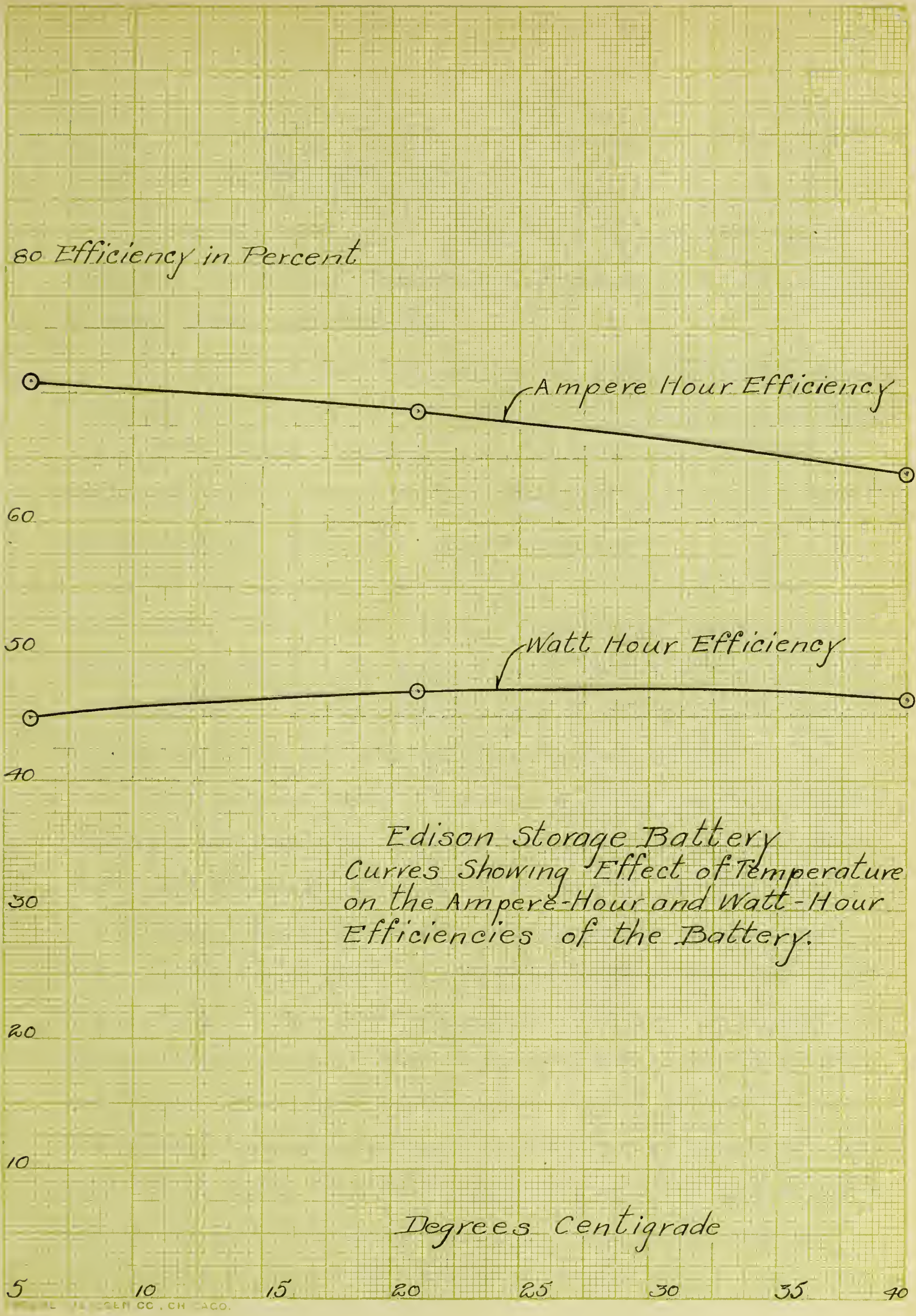


Edison Storage Battery
Curves Showing the Effect of Temperature on the Voltage Characteristics of of the Battery.



Edison Storage Battery Curves Showing Effect of Temperature on the Ampere-Hour and Watt Hour Input and Output of the Battery

... Z.EN CO., CHICAGO.


Edison Storage Battery
Curves Showing Effect of Temperature on the Ampere-Hour and Watt-Hour Efficiencies of the Battery.

RESISTANCE TESTS.

The object of this set of tests was to determine the change of the virtual internal resistance of the battery during a normal charge and discharge.

It is this factor with which we are most concerned, for it is the virtual internal resistance that is directly responsible for the internal dissipation of energy. What the true ohmic resistance of the battery is, it is not necessary for us to determine within the scope of this test.

This test followed the series of constant temperature tests; all of which were normal charges and discharges. The battery then having been charged and discharged three times at the normal rate, it was presumed that it would be in a normal working condition for beginning the present series.

An attempt was made during the various preceding tests to determine the change of internal resistance for each and every charge and discharge. This was first tried on discharge by momemtarily opening the switch and reading the electromotive force at intervals. Then the difference between the value thus found and the potential difference while current is passing would represent the I R drop in the cell due to its effective resistance. This value divided by the current rate would give the virtual internal resistance at the given point of discharge. This method had to be given up, however, as being impracticable due to the fact that when the circuit was again closed, the voltage did not come back immediately to its former value, but

rose slowly, thus introducing an error. An attempt was then made to determine the resistance by changing the rheostat and reducing the current from, say, the normal rate of charge at fifteen amperes down to, say, seven or eight amperes and reading the current and voltage. The current would then be raised to say twenty-five amperes and its value also that of the voltage read again. Then , by dividing the change in voltage by the change in current, we would get the virtual internal resistance for that point. This method, however, had also to be given up temporarily, for small errors were constantly creeping in in the voltage readings. To some extent, the same difficulty was experienced as in the first method.

It was finally decided to abandon the resistance readings entirely for the time, and run a separate test for that purpose at a later date. Eventually, in the following series of tests, the last enumerated method, in which the current was lowered and raised by means of the rheostat, was the one that was used.

It is noticed from an inspection of the resistance curve on discharge that the apparent internal resistance remains practically constant until the battery becomes practically discharged when the curve begins to rise very rapidly.

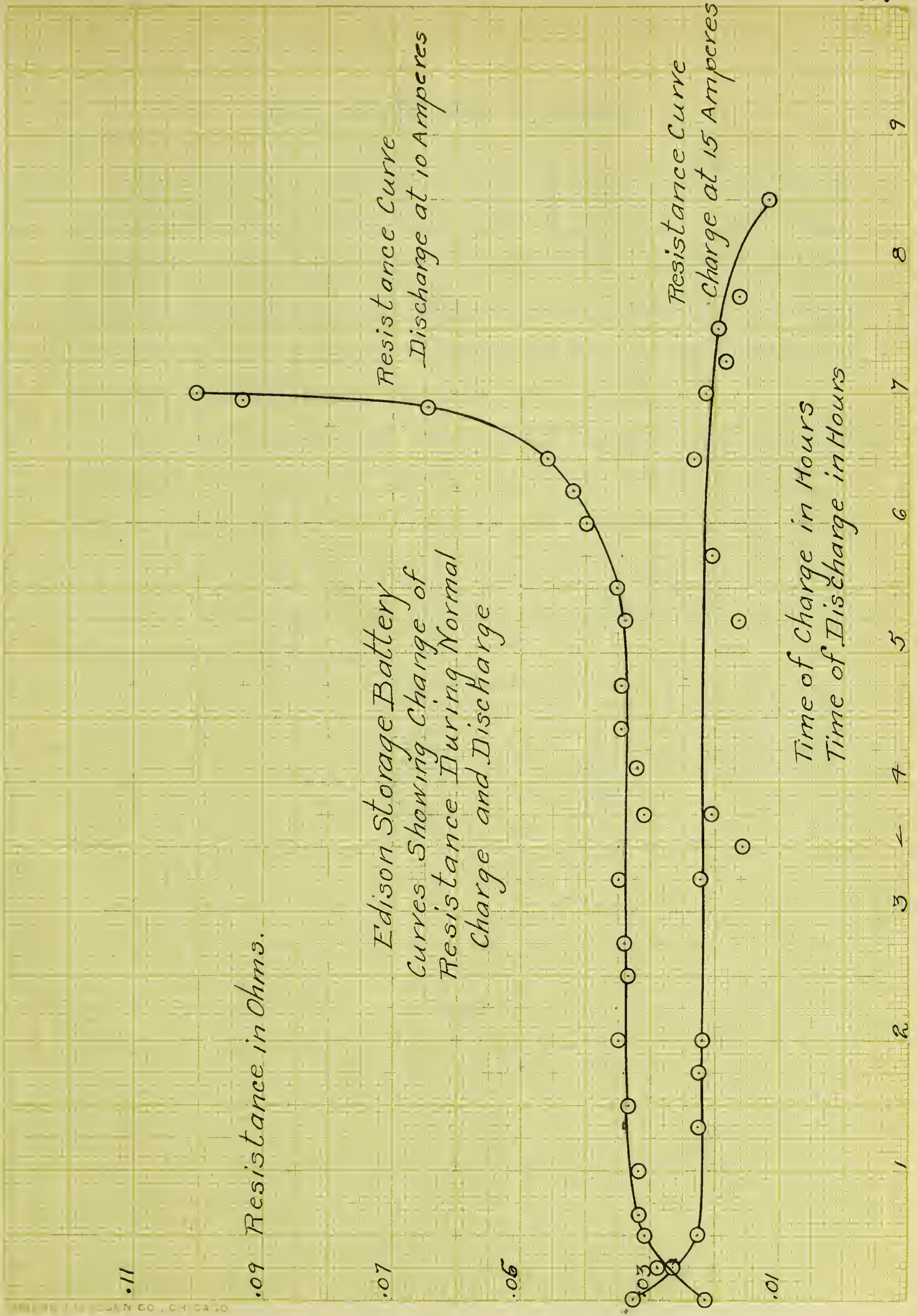
RESISTANCE TEST-CHARGE AT 15 AMPERES.

Time hr.-min.	I_1	E_1	I_2	E_2	I_1-I_2	E_1-E_2	R
0:00	20.0	8.70	5.00	8.21	15.00	.49	.0326
0:15	25.0	8.81	5.00	8.23	20.00	.58	.0290
0:30	21.0	8.62	7.00	8.30	14.00	.32	.0228
1:20	24.0	8.60	6.00	8.19	18.00	.41	.0227
I:45	22.0	8.60	10.00	8.33	12.00	.27	.0225
2:00	21.0	8.50	6.00	8.17	15.00	.33	.0220
3:15	19.2	8.63	9.80	8.42	9.40	.21	.0223
3:30	20.0	8.56	9.80	8.40	10.23	.16	.0156
4:00	22.2	8.58	9.50	8.46	12.70	.12	.0094
4:45	19.8	8.58	10.04	8.38	9.76	.20	.0204
5:15	20.0	8.68	10.07	8.52	9.93	.16	.0161
5:45	20.07	8.81	10.04	8.60	10.03	.21	.0204
6:30	22.3	8.94	7.80	8.60	14.50	.34	.0234
7:00	22.7	9.00	7.70	8.68	15.00	.32	.0213
7:15	22.5	8.95	7.80	8.68	14.70	.27	.0183
7:30	22.5	8.97	7.30	8.67	12.20	.30	.0197
7:45	22.7	8.95	7.40	8.70	15.30	.25	.0163
8:00	22.5	8.92	7.90	8.75	14.60	.17	.0115

RESISTANCE TEST - DISCHARGE AT 10 AMPERES.

Time hr.-min.	I_1	E_1	I_2	E_2	I_1-I_2	E_2-E_1	R
0:00	20.0	6.49	5.5	6.80	14.5	.31	.0214
0:15	17.5	6.44	5.5	6.76	12.0	.32	.0267
0:20	17.5	6.40	5.5	6.73	12.0	.33	.0275
0:30	15.5	6.37	5.5	6.71	11.0	.34	.0309
0:40	15.5	6.33	5.5	6.68	11.0	.35	.0318
0:50	15.5	6.30	5.5	6.65	11.0	.35	.0318
1:00	15.5	6.28	5.5	6.63	11.0	.35	.0318
1:30	16.0	6.18	5.5	6.53	10.5	.35	.0334
1:45	16.0	6.14	5.5	6.50	10.5	.36	.0343
2:00	16.0	6.12	6.0	6.47	10.0	.35	.0350
2:15	16.0	6.08	5.5	6.45	10.5	.37	.0353
2:30	16.0	6.07	5.5	6.42	10.5	.35	.0334
2:45	16.0	6.05	6.0	6.39	10.0	.34	.0340
3:00	16.0	6.02	6.0	6.38	10.0	.36	.0360
3:15	16.0	6.00	6.0	6.35	10.0	.35	.0350
3:30	15.5	6.00	5.5	6.35	10.0	.35	.0350
3:45	15.5	6.00	6.0	6.31	9.5	.31	.0308
4:10	17.5	5.88	7.5	6.20	10.0	.32	.0320
4:25	20.0	5.78	5.0	6.30	15.0	.52	.0347
4:45	20.0	5.73	5.0	6.25	15.0	.52	.0347
5:00	20.0	5.71	5.0	6.22	15.0	.51	.0340
5:15	20.0	5.67	5.0	6.18	15.0	.51	.0340
5:30	20.0	5.62	5.0	6.15	15.0	.53	.0353

Time hr.-min.	I_1	E_1	I_2	E_2	I_1-I_2	E_2-E_1	R
5:45	20.0	5.60	5.0	6.12	15.0	.52	.0347
6:00	20.0	5.49	5.0	6.09	15.0	.60	.0400
6:15	20.0	5.39	5.0	6.02	15.0	.63	.0420
6:30	20.0	5.28	5.0	5.96	15.0	.68	.0460
6:53	20.0	3.61	5.0	4.58	15.0	.97	.0647
6:55	20.0	3.42	5.0	4.43	15.0	1.01	.0673
6:57	20.0	2.90	5.0	4.30	15.0	1.40	.0933
7:00	20.0	2.60	5.0	4.15	15.0	1.55	.1033



Edison Storage Battery Curves Showing Change of Resistance During Normal Charge and Discharge

SHORT CIRCUIT TEST OF BATTERY.

The battery was charged for seven and one-half hours at the fifteen ampere rate, and allowed to stand two days. The battery was then short circuited through an ammeter for sixty minutes. There was an appreciable drop in the leads and ammeter as shown by the voltmeter attached directly to the elements. The current and voltage was noted every minute.

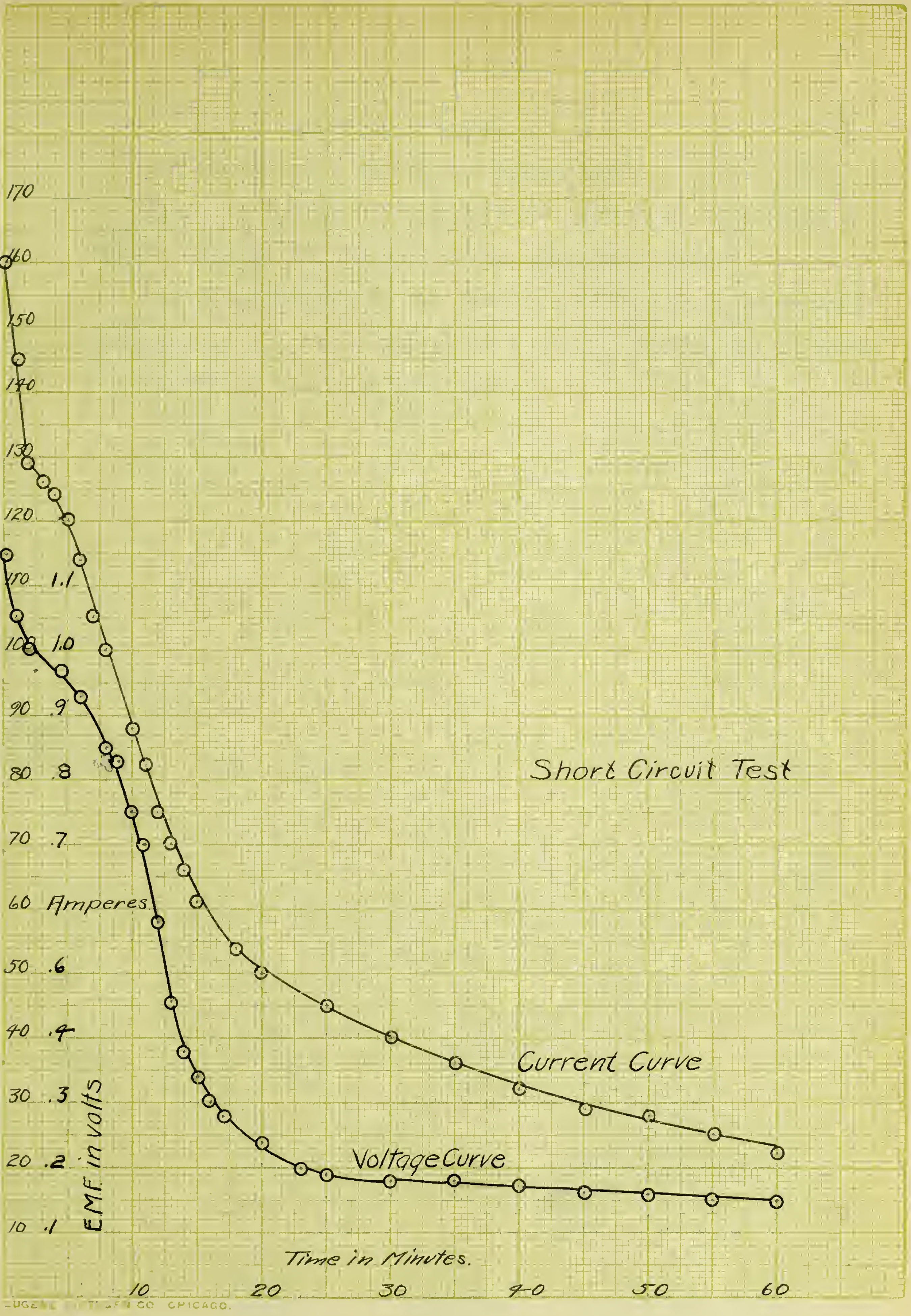
The cell suffered no apparant ill effects from this rough treatment. In fact, the makers claim that a short circuit improves the working conditions of the iron electrode, giving the cell stronger voltage. The amount of current was not far from what could have been predicted by dividing the voltage by the apparent resistance.

SHORT CIRCUIT TEST.

BATTERY CHARGED 7.5 HOURS AT 15 AMPERES.

Time	Time Min.	E	I
4:20 P.M.	0	1.15	160
4:21	1	1.05	145
4:22	2	1.00	129
4:23	3	.98	126
4:24	4	.97	124
4:25	5	.97	120
4:26	6	.93	114
4:27	7	.88	105
4:28	8	.85	100
4:29	9	.83	95
4:30	10	.75	88
4:31	11	.70	82
4:32	12	.58	75
4:33	13	.46	70
4:34	14	.38	66
4:35	15	.34	61
4:36	16	.30	58
4:37	17	.28	56
4:38	18	.27	54
4:39	19	.25	52
4:40	20	.24	50
4:41	21	.23	49

Time	Time Min.	E	I
4:43	23	.20	47
4:45	25	.19	45
4:50	30	.18	40
4:55	35	.18	36
5:00	40	.17	32
5:05	45	.16	29
5:10	50	.16	28
5:15	55	.15	25
5:20	60	.15	22


Short Circuit Test
Current Curve
Voltage Curve
170
160
150
140
130
120
110 1.1
100 1.0
90 .9
80 .8
70 .7
60 Amperes.
50 .6
40 .4
30 .3
20 .2
10 .1
E.M.F. in volts
Time in Minutes.
10
20
30
40
50
60

GENERAL SUMMARY.

The tests, as a whole, are summarized in the following two pages, in which, for purposes of comparison, the various inputs, outputs and capacities are grouped together.

The tests follow in the order in which they were actually performed in the experimental part of the subject and in which they appear in the completed work.

TEST NO.	CH. AMP.	DIS. AMP.	A. H. INPUT	A.H. OUTPUT	W. H. Input	W. H. OUTPUT	COEF. OF DROP.
1	15	10	150.0	89.0	1330	518	.657
2	15	10	113.6	89.7	982	528	.683
3	15	30	107.5	69.8	885	359	.587
4	15	30	103.5	75.0	859	391.5	.628
5	20	30	105.0	83.4	932	454	.612
6	30	30	105.0	75.5	942	416	.615
7	15	10	91.0	63.8	812	361	.633
8	15	10	111.3	76.5	948	447	.683
9	15	10	137.5	87.7	1130	523	.727

TEST NO.	CH. AMP.	DIS. AMP.	A. H. EFF.	W. H. EFF.	TIME OF CH.-HR.	TIME OF DIS.-HR.	TEMP. DEG. C.
1	15	10	59.40	39.0	10.00	8.90	____
2	15	10	79.00	54.0	7.58	8.97	____
3	15	30	65.00	38.1	7.15	2.33	____
4	15	30	72.50	45.6	6.88	2.50	____
5	20	30	79.40	48.7	5.25	2.78	____
6	30	30	72.00	44.2	3.50	2.52	____
7	15	10	71.00	44.9	6.07	6.38	7
8	15	10	68.75	47.0	7.42	7.65	21
9	15	10	63.75	46.3	9.17	8.77	40

GENERAL CONCLUSIONS.

The capacity and efficiency of the Edison storage battery varies, for the most part, with four quantities, the rate and length of charge, the rate of discharge and the temperature at which charge and discharge takes place.

The effect of the length of charge upon the efficiency is admirably illustrated in tests No. 1 and No. 2. In test No. 1 the charge ran for 10 hours as against 7.58 hours in test No.2. In test No. 1, the ampere hour and watt-hour efficiencies are respectively 59.4 % and 39 % as against ampere hour and watt-hour efficiencies equal respectively to 79 % and 54 % in test No. 2. Thus, it is seen that the efficiencies are high with very short charges and very low with very long charges.

The effect of the rate of charge on the efficiencies may be observed in tests No.2, No. 5 and No. 6. Test No. 2 is probably a fair test inasmuch as it followed directly after two other normal rate charges and discharges. The charge in this test took place at fifteen amperes while in tests No. 5 and No.6, the charging rate was 20 and 30 amperes respectively. In test No.2, where the charging rate was 15 amperes, we get ampere hour and watt-hour efficiencies equal respectively to 79 % and 54 %. In test No. 5, where the charging rate was 20 amperes, we get ampere hour and watt-hour efficiencies equal respectively to 79.4 % and 48.7 %. Also, in test No. 6, where the charging rate was 30 amperes, the ampere hour and watt-hour efficiencies are equal respectively to 72 % and 44.2 %. Thus, it is seen that the watt-hour efficiency decreases as the

charging rate increases. As for the ampere hour efficiency, the 30 ampere rate gives a lower efficiency than the 15 ampere rate, but the 20 ampere rate is slightly higher. This test, at any rate, probably gave an efficiency that was a little too high inasmuch as it followed the series of high discharge tests. It is probably safe to say, however, as in the case of the watt-hour efficiency, that as the charging rate increases above normal, the ampere hour efficiency decreases.

The effect of the rate of discharge on the efficiency is clearly shown in tests No. 2 and No. 3. Test No.2 followed Test No. 1, which was a normal charge and discharge, and test No.3 followed test No. 2, which was a normal charge and discharge so that the battery was probably in normal condition for each of these tests which it is safe to say are accordingly, fair tests. In test No. 2, we get an ampere hour and watt-hour efficiency equal respectively to 79 % and 54 %, while in test No. 3, we get an ampere hour and watt-hour efficiency equal, respectively to 65 % and 38.1 %. Thus, it is seen that as the rate of discharge increases above normal, the ampere hour and watt-hour efficiencies decrease very rapidly.

The effect of temperature on the efficiencies of the battery is clearly shown in tests No. 7, No. 8 and No. 9, all of which were run at constant temperature. These tests followed a normal charge and discharge so that the battery was in good working condition. The effects of temperature, in this case, can best be seen by referring to plate No. 6. In test No. 7, in which the temperature was held constant at 7 degrees centigrade, the ampere hour and watt-hour efficiencies are equal,

respectively, to 71 % and 44.9 %. In test No. 8, in which the temperature was held constant at 21 degrees centigrade, the ampere hour and watt-hour efficiencies are equal respectively to 68.75 % and 47 %. In test No. 9, in which the temperature was held constant at 40 degrees centigrade, the ampere hour and watt-hour efficiencies are equal respectively to 63.75 % and 46.25 %. Thus, it is seen that as the temperature increases, the ampere hour efficiency decreases, while the watt-hour efficiency increases slightly at first and then begins to decrease.

Tests No. 3, No. 5 and No. 6 might show something as to the output at different rates of charging. Test No. 6, at the 30 ampere rate, appears to give a slightly higher output, both in ampere hours and watt-hours than No. 3 at the 15 ampère rate. Test No. 5 gives values slightly higher, but these values are somewhat in doubt. It would seem, however, on the whole, by inspecting the data, that the output increases, to some extent, as the charging rate increases.

The effect of the rate of discharge on the output is easily seen in tests No. 2 and No. 3. In test No. 2, at the 10 ampere rate, the ampere hour and watt-hour outputs equal respectively, 89.7 and 528. In test No. 3 at the 30 ampere rate, the ampere hour and watt-hour outputs equal respectively 69.8 and 359. Thus, it may be seen that both outputs are lowered very materially by the increase in the charging rate.

The effect of temperature on the output is easily seen in tests No. 7, No. 8 and No. 9. From test No. 7, at seven

degrees centigrade, to test No. 9, at 40 degrees centigarde, the ampere hour output increases from 63.8 ampere hours to 87.67 ampere hours, while the watt-hour output increases from 361 watt-hours to 523 watt-hours. The ampere hour and watt-hour outputs increase in almost a direct ratio with the increase in temperature between the two limits tested.

It is significant to note that in only four tests out of the nine, No. 1, No. 2, No. 5 and No. 9 was the rated output of the battery exceeded or even equaled. In most cases also, the makers claim a higher efficiency for the battery than was actually gotten. Test No. 2 which charged for nine hours at 15 amperes and discharged at 10 amperes, appears to give about the best test for all practical purposes of any recorded.

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